

Strong decays of the $X(2500)$ newly observed by the BESIII Collaboration

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Basing on the observation of a new $J^{PC} = 0^{-+}$ state, $X(2500)$, in the partial wave analysis of the decay $J/\psi \rightarrow \gamma X \rightarrow \gamma \phi \phi$ performed by the BESIII Collaboration, we have evaluated the strong decays of the $X(2500)$ as the 4^1S_0 and 5^1S_0 $s\bar{s}$ states in the 3P_0 model of meson decay. The predicted total decay width for the 4^1S_0 $s\bar{s}$ is about 894.5 MeV, and the one for the 5^1S_0 $s\bar{s}$ is about 271.1 MeV, which is in agreement with the experimental data $\Gamma_{X(2500)} = 230^{+64+56}_{-35-33}$ MeV. By considering the mass and the total strong decay width of the $X(2500)$, we propose that the $X(2500)$ state can be interpreted as a candidate of the 5^1S_0 $s\bar{s}$ state.

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I. INTRODUCTION

Recently, the BESIII Collaboration has preformed a partial wave analysis of the decay $J/\psi \rightarrow \gamma X \rightarrow \gamma \phi \phi$ to study the intermediate states [1]. Besides the confirmation of the $\eta(2225)$, two additional pseudoscalar states, $\eta(2100)$ and $X(2500)$, are also reported. The $\eta(2100)$ has been listed in Particle Data Group book as the further state [2], which was found in the $J/\psi \rightarrow 4\pi\gamma$ process [3]. The $X(2500)$ is the newly observed state with the significance of 8.8σ , and the mass and decay width are

$$\begin{aligned} M_{X(2500)} &= 2470^{+15+101}_{-19-23} \text{ MeV}, \\ \Gamma_{X(2500)} &= 230^{+64+56}_{-35-33} \text{ MeV}. \end{aligned} \quad (1)$$

In the light pseudoscalar sector, the 1^1S_0 meson nonet (π, η, η' , and K) as well as the 2^1S_0 members [$\pi(1300)$, $\eta(1295)$, $\eta(1475)$, and $K(1460)$] have been well established [2]. In the Refs. [4–6], the $\pi(1800)$ and $K(1830)$, together with the $X(1835)$ and $\eta(1760)$ observed by the BES Collaboration [7, 8], are suggested to constitute the 3^1S_0 meson nonet. In addition, the $\pi(2070)$, $\eta(2100)$ and $\eta(2225)$ are interpreted as the members of the 4^1S_0 meson nonet in Refs. [6, 9, 10]. The $X(2370)$ observed in $J/\psi \rightarrow \gamma\pi^+\pi^-\eta$ [11] was suggested to be a good isoscalar candidate of the 5^1S_0 nonet [6], and the $\pi(2360)$ observed in a partial wave analysis of $p\bar{p} \rightarrow \eta\eta\pi$ process [12] was interpreted to be the isovector candidate of the 5^1S_0 nonet [13].

It is suggested that the light mesons could be grouped into the following Regge trajectories[14]

$$M_n^2 = M_0^2 + (n-1)\mu^2, \quad (2)$$

where M_0 is the lowest-lying meson mass, n is the radial quantum number, and μ^2 is the slope parameter of the corresponding trajectory. In Fig. 1, we plot the

0^{-+} trajectory on the plane of (n, M^2) adopting the relation of Eq. (2). It shows that the η , $\eta(1295)$, $\eta(1760)$, $\eta(2100)$, and $X(2370)$ (π , $\pi(1300)$, $\pi(1800)$, $\pi(2070)$, and $\pi(2360)$) can be well accommodated into a trajectory of the isoscalar (isovector) states, and the η' , $\eta(1475)$, $X(1835)$, $\eta(2225)$, and $X(2500)$ approximately populate a common trajectory, which suggests that, in the presence of the $X(2370)$ being the 5^1S_0 isoscalar state [6], the $X(2500)$ could be another 5^1S_0 isoscalar state. If one accepts that the $\pi(2360)$, $X(2370)$, and $X(2500)$ belong to the 5^1S_0 meson nonet, the nearly degenerate masses of the $X(2370)$ and the $\pi(2360)$ would imply that the $X(2370)$ is mainly $(u\bar{u} - d\bar{d})/\sqrt{2}$. No observation of the $X(2370)$ state in the $J/\psi \rightarrow \gamma\phi\phi$ process [1] favors this argument. Therefore, as the orthogonal partner of the $X(2370)$, the $X(2500)$ could be treated as the 5^1S_0 $s\bar{s}$ state based on its mass [15].

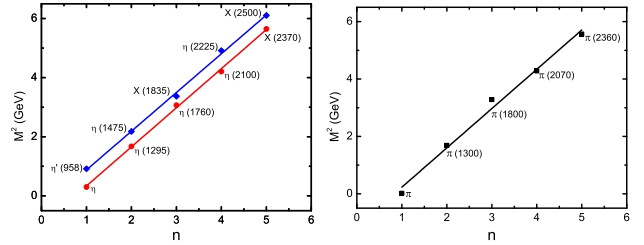


FIG. 1: The Regge trajectories for the n^1S_0 meson mass spectrum with $M^2 = M_0^2 + (n-1)\mu^2$ ($\mu^2 = 1.31, 1.32, 1.36 \text{ GeV}^2$ for the η' , η , and π -trajectories, respectively). The masses of $\eta(2100)$, $\eta(2225)$, and $X(2500)$ are from the BESIII results [1], the $X(2370)$ mass is from the BESIII results [11]. All the other states masses are taken from PDG [2]

The mass information alone is insufficient to identify the $X(2500)$ as the pseudoscalar meson excitation, because the mass of the lowest pseudoscalar glueball predicted by the Lattice QCD is in the range of 2.3~2.6 GeV [16–18], which is also in consistent with the $X(2500)$ mass. We shall discuss the possibility of the $X(2500)$ being the ordinary 5^1S_0 $s\bar{s}$ by studying its strong decay properties. It is natural and necessary to exhaust the possible $q\bar{q}$ descriptions of a newly observed state before

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restoring to the more exotic assignments.

In this work we study the strong decays of the $X(2500)$ in the 3P_0 model of meson decay, assuming it being the 5^1S_0 $s\bar{s}$ state. The 4^1S_0 $s\bar{s}$ assignment of the $X(2500)$ is also discussed. We calculate the partial decay widths and total decay width by taking into account 21 decay channels, and discuss the dependence of predictions on the $X(2500)$ mass. Our result of the total decay width of $X(2500)$ indicates that the $X(2500)$ can be regarded as the candidate of the 5^1S_0 $s\bar{s}$ state.

This paper is organized as follows. In Sec. II, we will present a brief review of the 3P_0 model of meson decay. The results and the discussions of the strong decays of the $X(2500)$ state are shown in Sec. III. Finally, the summary is given in Sec. IV.

II. THE 3P_0 MODEL OF MESON DECAY

In this section, we will give a brief introduction of the 3P_0 model. The 3P_0 model, also known as the quark-pair creation model (QPC), was originally introduced by Micu [19] and further developed by Le Yaouanc *et al.* [20–24], and has been widely applied to study hadron strong decays with considerable success [25–46].

In the 3P_0 model, the strong decays occur by producing a quark-antiquark pair with the vacuum quantum number $J^{PC} = 0^{++}$. The newly produced quark-antiquark pair, together with the $q\bar{q}$ within the initial hadron, re-groups into two outgoing hadrons in all possible quark rearrangement ways. The decays process for the meson case can be depicted in Fig. 2

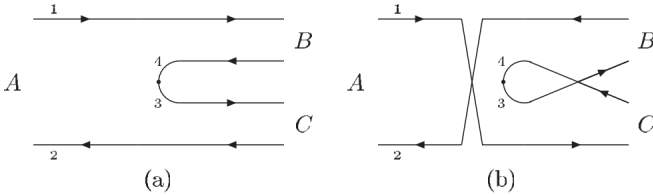


FIG. 2: The two possible diagrams contributing to $A \rightarrow BC$ in the 3P_0 model: (a) the quark within the meson A combines with the created antiquark to form the meson B, the antiquark within in the meson A combines with the created quark to form the meson C; (b) the quark within the meson A combines with the created antiquark to form the meson C, the antiquark within the meson A combines with the created quark to form the meson B.

For the meson decay process,

$$A(P_A) \rightarrow B(P_B) + C(P_C), \quad (3)$$

the transition operator T can be written by,

$$T = -3\gamma \sum_m \langle 1m \, 1-m | 00 \rangle \int d^3\vec{p}_3 d^3\vec{p}_4 \delta^3(\vec{p}_3 + \vec{p}_4) \mathcal{Y}_1^m \left(\frac{\vec{p}_3 - \vec{p}_4}{2} \right) \chi_{1-m}^{34} \phi_0^{34} \omega_0^{34} b_3^\dagger(\vec{p}_3) d_4^\dagger(\vec{p}_4), \quad (4)$$

where the dimensionless parameter γ represents the probability of the quark-antiquark pair with $J^{PC} = 0^{++}$ creation from the vacuum, \vec{p}_3 (\vec{p}_4) is the momentum of the created quark (antiquark) q_3 (q_4), and ϕ_0^{34} , ω_0^{34} , and χ_{1-m}^{34} are the flavor, color, and spin wave functions of the $q_3\bar{q}_4$ pair, respectively. The solid harmonic polynomial $\mathcal{Y}_1^m(\vec{p}) \equiv |p|^1 Y_1^m(\theta_p, \phi_p)$ reflects the momentum-space distribution of the $q_3\bar{q}_4$ pair.

The helicity amplitude $\mathcal{M}^{M_{JA} M_{JB} M_{JC}}(\vec{P})$ is defined as,

$$\langle BC | T | A \rangle = \delta^3(\vec{P}_A - \vec{P}_B - \vec{P}_C) \mathcal{M}^{M_{JA} M_{JB} M_{JC}}(\vec{P}), \quad (5)$$

where \vec{P}_A , \vec{P}_B , and \vec{P}_C are the 3-momentum of the mesons A, B, and C, respectively. The $|A\rangle$, $|B\rangle$, and $|C\rangle$ denote the mock meson states, and the mock meson $|A\rangle$ is defined by [47]

$$\begin{aligned} & |A(n_A^{2S_A+1} L_A J_A M_{JA})(\vec{P}_A) \rangle \\ & \equiv \sqrt{2E_A} \sum_{M_{L_A}, M_{S_A}} \langle L_A M_{L_A} S_A M_{S_A} | J_A M_{JA} \rangle \\ & \times \int d^3\vec{p}_A \psi_{n_A L_A M_{L_A}}(\vec{p}_A) \chi_{S_A M_{S_A}}^{12} \phi_A^{12} \omega_A^{12} \\ & \times \left| q_1 \left(\frac{m_1}{m_1 + m_2} \vec{P}_A + \vec{p}_A \right) \bar{q}_2 \left(\frac{m_2}{m_1 + m_2} \vec{P}_A - \vec{p}_A \right) \right\rangle, \end{aligned} \quad (6)$$

where m_1 and m_2 (\vec{p}_1 and \vec{p}_2) are the masses (momenta) of the quark q_1 and the antiquark \bar{q}_2 , respectively; $\vec{P}_A = \vec{p}_1 + \vec{p}_2$, $\vec{p}_A = (m_2 \vec{p}_1 - m_1 \vec{p}_2)/(m_1 + m_2)$; $\chi_{S_A M_{S_A}}^{12}$, ϕ_A^{12} , ω_A^{12} , and $\psi_{n_A L_A M_{L_A}}(\vec{p}_A)$ are the spin, flavor, color, and space wave functions of the meson A composed of $q_1\bar{q}_2$ with total energy E_A , respectively. n_A is the radial quantum number of the meson A. $S_A = s_{q_1} + s_{\bar{q}_2}$, $J_A = L_A + S_A$, s_{q_1} ($s_{\bar{q}_2}$) is the spin of q_1 (\bar{q}_2), and L_A is the relative orbital angular momentum between q_1 and \bar{q}_2 . $\langle L_A M_{L_A} S_A M_{S_A} | J_A M_{JA} \rangle$ is a Clebsch-Gordan coefficient. The mock meson satisfies the normalization condition,

$$\begin{aligned} & \langle A(n_A^{2S_A+1} L_A J_A M_{JA})(\vec{p}_A) | A(n_A^{2S_A+1} L_A J_A M_{JA})(\vec{p}'_A) \rangle \\ & = 2E_A \delta^3(\vec{p}_A - \vec{p}'_A). \end{aligned} \quad (7)$$

In the center of mass frame (c.m.) of meson A, the explicit form of the helicity amplitude can be written as,

$$\begin{aligned} & \mathcal{M}^{M_{JA} M_{JB} M_{JC}}(\vec{P}) = \gamma \sqrt{8E_A E_B E_C} \\ & \times \sum_{M_{L_A}} \sum_{M_{S_A}} \sum_{M_{L_B}} \sum_{M_{S_B}} \sum_{M_{L_C}} \sum_{M_{S_C}} \sum_m \langle L_A M_{L_A} S_A M_{S_A} | J_A M_{JA} \rangle \\ & \times \langle L_B M_{L_B} S_B M_{S_B} | J_B M_{JB} \rangle \langle L_C M_{L_C} S_C M_{S_C} | J_C M_{JC} \rangle \\ & \times \langle 1m \, 1-m | 00 \rangle \langle \chi_{S_B M_{S_B}}^{14} \chi_{S_C M_{S_C}}^{32} | \chi_{S_A M_{S_A}}^{12} \chi_{1-m}^{34} \rangle \\ & \times [\mathbf{f}_1 I(\vec{P}, m_1, m_2, m_3) \\ & + (-1)^{1+S_A+S_B+S_C} \mathbf{f}_2 I(-\vec{P}, m_2, m_1, m_3)], \end{aligned} \quad (8)$$

where the two terms $\mathbf{f}_1 = \langle \phi_B^{14} \phi_C^{32} | \phi_A^{12} \phi_0^{34} \rangle$ and $\mathbf{f}_2 = \langle \phi_B^{32} \phi_C^{14} | \phi_A^{12} \phi_0^{34} \rangle$ correspond to the contributions from

Fig. 2(a) and Fig. 2(b), respectively, and the momentum space integral is,

$$\begin{aligned}
& I(\vec{P}, m_1, m_2, m_3) \\
&= \int d^3\vec{p} \psi_{n_B L_B M_{L_B}}^* \left(\frac{m_3}{m_1 + m_2} \vec{P}_B + \vec{p} \right) \\
&\quad \times \psi_{n_C L_C M_{L_C}}^* \left(\frac{m_3}{m_2 + m_3} \vec{P}_B + \vec{p} \right) \\
&\quad \times \psi_{n_A L_A M_{L_A}} \left(\vec{P}_B + \vec{p} \right) \mathcal{Y}_1^m(\vec{p}), \quad (9)
\end{aligned}$$

where $\vec{P} = \vec{P}_B = -\vec{P}_C$, $\vec{p} = \vec{p}_3$, and ψ is the meson wave function in momentum space. The spin overlap in terms of $9j$ symbol can be given by

$$\begin{aligned}
& \langle \chi_{S_B M_{S_B}}^{14} \chi_{S_C M_{S_C}}^{32} | \chi_{S_A M_{S_A}}^{12} \chi_{1-m}^{34} \rangle = \\
& \times \sum_{S, M_S} \langle S_B M_{S_B} S_C M_{S_C} | S M_S \rangle \\
& \times \langle S_A M_{S_A} 1 - m | S M_S \rangle (-1)^{S_C+1} \\
& \times \sqrt{3(2S_A+1)(2S_B+1)(2S_C+1)} \\
& \times \left\{ \begin{array}{ccc} 1/2 & 1/2 & S_A \\ 1/2 & 1/2 & 1 \\ S_B & S_C & S \end{array} \right\} \quad (10)
\end{aligned}$$

The partial wave amplitude $\mathcal{M}^{LS}(\vec{P})$ can be obtained from the helicity amplitude,

$$\begin{aligned}
\mathcal{M}^{LS}(\vec{P}) &= \sum_{M_{J_B}} \sum_{M_{J_C}} \sum_{M_S} \sum_{M_L} \langle L M_L S M_S | J_A M_{J_A} \rangle \\
&\quad \langle J_B M_{J_B} J_C M_{J_C} | S M_S \rangle \\
&\quad \times \int d\Omega \mathcal{Y}_{L M_L}^* \mathcal{M}^{M_{J_A} M_{J_B} M_{J_C}}(\vec{P}), \quad (11)
\end{aligned}$$

Because of different choices of pair-production vertex, phase space convention, employed meson wave function, various 3P_0 models exist in literatures. In this article, we restrict to the simplest vertex as introduced originally by Micu [19] which assumes a spatially constant pair-production strength γ , adopt the relativistic phase space, and employ the simple harmonic oscillator (SHO) approximation for the meson space wave functions which are commonly used in evaluating the light mesons strong decays [4, 6, 9, 10, 33–35]. With the relativistic phase space, the decay width $\Gamma(A \rightarrow BC)$ can be expressed as follows,

$$\Gamma(A \rightarrow BC) = \frac{\pi |\vec{P}|}{4M_A^2} \sum_{L,S} \left| \mathcal{M}^{LS}(\vec{P}) \right|^2, \quad (12)$$

where M_A , M_B , and M_C are the masses of the meson A , B , and C , respectively, and

$$|\vec{P}| = \frac{\sqrt{[M_A^2 - (M_B + M_C)^2][M_A^2 - (M_B - M_C)^2]}}{2M_A}. \quad (13)$$

TABLE I: Decay widths of the 5^1S_0 and 4^1S_0 $s\bar{s}$ states in the 3P_0 model (in MeV). The initial state mass is set to 2470 MeV.

Channel	i	Mode	$\Gamma_i(4^1S_0)$	$\Gamma_i(5^1S_0)$
$0^- \rightarrow 0^- 0^+$	ch1	$\eta f_0(980)$	4.03	0.04
	ch2	$\eta' f_0(980)$	7.31	1.62
	ch3	$\eta(1475) f_0(980)$	13.46	18.85
	ch4	$\eta f_0(1710)$	2.89	1.23
$0^- \rightarrow 1^- 1^-$	ch5	$\phi(1020) \phi(1020)$	2.46	0.01
$0^- \rightarrow 0^- 2^+$	ch6	$\eta f_2'(1525)$	57.84	9.61
$0^- \rightarrow 0^- 0^+$	ch7	$K K_0^*(1430)$	11.00	1.17
	ch8	$K K_0^*(1950)$	31.78	22.22
$0^- \rightarrow 1^- 1^+$	ch9	$K^* K_1(1270)$	35.42	8.76
	ch10	$K^* K_1(1400)$	86.66	18.13
$0^- \rightarrow 0^- 1^-$	ch11	$K K^*$	9.13	0.06
	ch12	$K(1460) K^*$	119.20	29.43
	ch13	$K K^*(1410)$	7.80	13.38
	ch14	$K K^*(1680)$	6.93	2.29
	ch15	$K K(1830)$	116.98	72.21
$0^- \rightarrow 1^- 1^-$	ch16	$K^* K^*$	15.68	1.37
	ch17	$K^* K^*(1410)$	223.77	42.44
$0^- \rightarrow 0^- 2^+$	ch18	$K K_2^*(1430)$	37.30	0.43
	ch19	$K K_2^*(1980)$	0.01	0.01
$0^- \rightarrow 1^- 2^+$	ch20	$K^* K_2^*(1430)$	83.36	18.59
$0^- \rightarrow 0^- 3^-$	ch21	$K K_3^*(1780)$	21.44	9.25
Total width			894.45	271.10
BESIII data			230_{-35}^{+64+56}	

Under the SHO approximation, the meson space wave function is

$$\psi_{n L M_L}(\mathbf{p}) = R_{nL}^{\text{SHO}}(p) \mathcal{Y}_{L M_L}(\Omega_p), \quad (14)$$

where the radial wave function is given by

$$\begin{aligned}
R_{nL}^{\text{SHO}}(p) &= \frac{(-1)^n (-i)^L}{\beta^{3/2}} \sqrt{\frac{2n!}{\Gamma(n+L+3/2)}} \\
&\quad \times \left(\frac{p}{\beta} \right)^L e^{-(p^2/2\beta^2)} L_n^{L+(1/2)} \left(\frac{p^2}{\beta^2} \right) \quad (15)
\end{aligned}$$

Here β is the SHO wave function scale parameter, and $L_n^{L+(1/2)}(p^2/\beta^2)$ is an associated Laguerre polynomial.

III. DECAYS OF THE 4^1S_0 AND 5^1S_0 $s\bar{s}$ STATES IN THE 3P_0 MODEL

The parameters used in the 3P_0 model involve the $q\bar{q}$ pair production strength parameter γ , the SHO wave function scale parameter β , and the masses of the constituent quark. In this work, we choose to follow the Refs. [10, 36, 45] and take $\gamma = 8.77$, $\beta_A = \beta_B =$

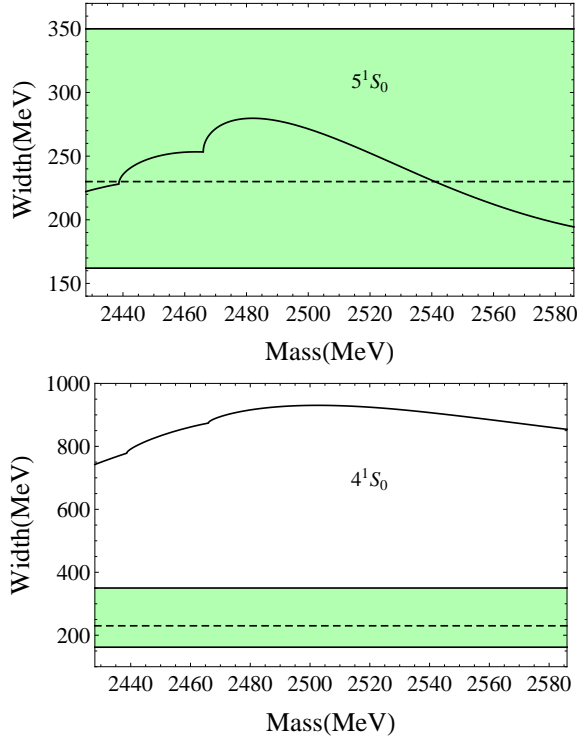


FIG. 3: The dependence of the total widths of the 5^1S_0 and 4^1S_0 $s\bar{s}$ states on the initial state mass in the 3P_0 decay model. The dashed line with a green band denotes the BESIII data.

$\beta_C = \beta = 400$ MeV, $m_u = m_d = 330$ MeV, and $m_s = 550$ MeV¹. The meson masses used in this work are $M_\eta = 547.86$ MeV, $M_{\eta'} = 957.793$ MeV, $M_{\eta(1295)} = 1294.4$ MeV, $M_{\eta(1475)} = 1476$ MeV, $M_{f_0(980)} = 990$ MeV, $M_{f_0(1710)} = 1723$ MeV, $M_{\phi(1020)} = 1019.46$ MeV, $M_{f'_2(1525)} = 1525$ MeV, $M_K = 493.68$ MeV, $M_{K_0^*(1430)} = 1425$ MeV, $M_{K_0^*(1950)} = 1945$ MeV, $M_{K^*} = 891.66$ MeV, $M_{K_1(1270)} = 1272$ MeV, $M_{K_1(1400)} = 1403$ MeV, $M_{K(1460)} = 1460$ MeV, $M_{K(1830)} = 1830$ MeV, $M_{K^*(1410)} = 1414$ MeV, $M_{K^*(1680)} = 1717$ MeV, $M_{K_2^*(1430)} = 1425.6$ MeV, $M_{K_2^*(1980)} = 1973$ MeV, $M_{K_3^*(1780)} = 1776$ MeV [2]. The meson flavor wave functions follow the conventions of Ref. [35].

With the above inputs, the decay widths of the $X(2500)$ as the 4^1S_0 and 5^1S_0 $s\bar{s}$ states are listed in Table I. The predicted total width of the $X(2500)$ as the 5^1S_0 $s\bar{s}$ state is 271.1 MeV, in agreement with the experiment data $\Gamma_{X(2500)} = 230^{+64+56}_{-35-33}$ MeV within errors. If the $X(2500)$ is the 4^1S_0 $s\bar{s}$ state, its total width is predicted to be about 894.5 MeV, much larger than the experimental data. The dependence of the predicted decay widths of the $X(2500)$ as the 4^1S_0 and 5^1S_0 $s\bar{s}$ on the

initial state mass is shown in Fig. 3. As shown in Fig. 3, when the initial state mass varies from 2428 to 2580 MeV, the total width of the 5^1S_0 $s\bar{s}$ state varies from 194 to 280 MeV, lying in the width range of the $X(2500)$, while the total width of the 4^1S_0 $s\bar{s}$ state varies from 740 to 932 MeV, far more than the $X(2500)$ width. Therefore, it is difficult to explain the $X(2500)$ as the 4^1S_0 $s\bar{s}$ state, but the assignment of the $X(2500)$ as the 5^1S_0 $s\bar{s}$ state appears reasonable.

The smaller total decay width for the 5^1S_0 assignment compared with the 4^1S_0 assignment can be understood via the node structure of the wave function of the initial state. The nodes of the 5^1S_0 state is more than that of the 4^1S_0 state, and the overlap of the 5^1S_0 state with the low-lying final states is smaller, which results in the smaller amplitude of the decay process. Hence, with the same phase space, the total decay width of the 4^1S_0 state is much larger than that of the 5^1S_0 state.

The dependence of the partial strong decay widths of the $X(2500)$ as both 4^1S_0 and 5^1S_0 $s\bar{s}$ on the initial state mass is also presented in Fig. 4, where the results for the 5^1S_0 and 4^1S_0 $s\bar{s}$ assignments are plotted in the left and right panels, respectively, and the curves labeled "chi" stand for the results for the i decay channels of Table I. For both 5^1S_0 and 4^1S_0 $s\bar{s}$ states, the partial widths of the $\eta(1475)f_0(980)$, $KK_0^*(1950)$ and $K^*K^*(1400)$ channels are sensitive to the initial state mass.

The new pseudoscalar state $X(2500)$ has been observed in the decay $J/\psi \rightarrow \gamma X \rightarrow \gamma \phi \phi$ [1], however, the branching ratio of the $\phi\phi$ channel is predicted to be very small. So, in order to confirm or refute the possibility of the $X(2500)$ being the 5^1S_0 $s\bar{s}$ state, the further confirmation of this small branching ratio is strongly called for.

Also, since only the $\phi\phi$ decay mode of the $X(2500)$ has been observed, an important test of this interpretation of the $X(2500)$ as 5^1S_0 $s\bar{s}$ would be the observation of some of these other decay modes with large branching ratios such as $KK(1830)$, $K^*K^*(1410)$, $K^*K(1460)$, $KK_0^*(1950)$, $K^*K_2^*(1430)$, $\eta(1475)f_0(980)$, and $K^*K_1(1400)$.

IV. SUMMARY AND CONCLUSION

We have calculated the strong decay of the $X(2500)$ state with the assignments of 4^1S_0 and 5^1S_0 $s\bar{s}$ in the 3P_0 model. The predicted total width for the 4^1S_0 $s\bar{s}$ is far from the the observed width of the $X(2500)$, while the one for the 5^1S_0 $s\bar{s}$ is in good agreement with the experimental data. The mass of the 5^1S_0 $s\bar{s}$ quantitatively estimated by Regge phenomenology is about 2.5 MeV [14, 15], which is also consistent with the observed mass of the $X(2500)$. Therefore, The available experimental evidence for the $X(2500)$ is in favor of the 5^1S_0 interpretation. To test this assignment, the further confirmation of the small branching ratio of $\phi\phi$ channel and the further information of other decay modes such as $KK(1830)$, $K^*K^*(1410)$,

¹ Our value of γ is higher than that used by Ref. [36] (0.505) by a factor of $\sqrt{96\pi}$, due to different filed conventions, constant factors in the transition operator T , etc. The calculated results of the widths are, of course, affected.

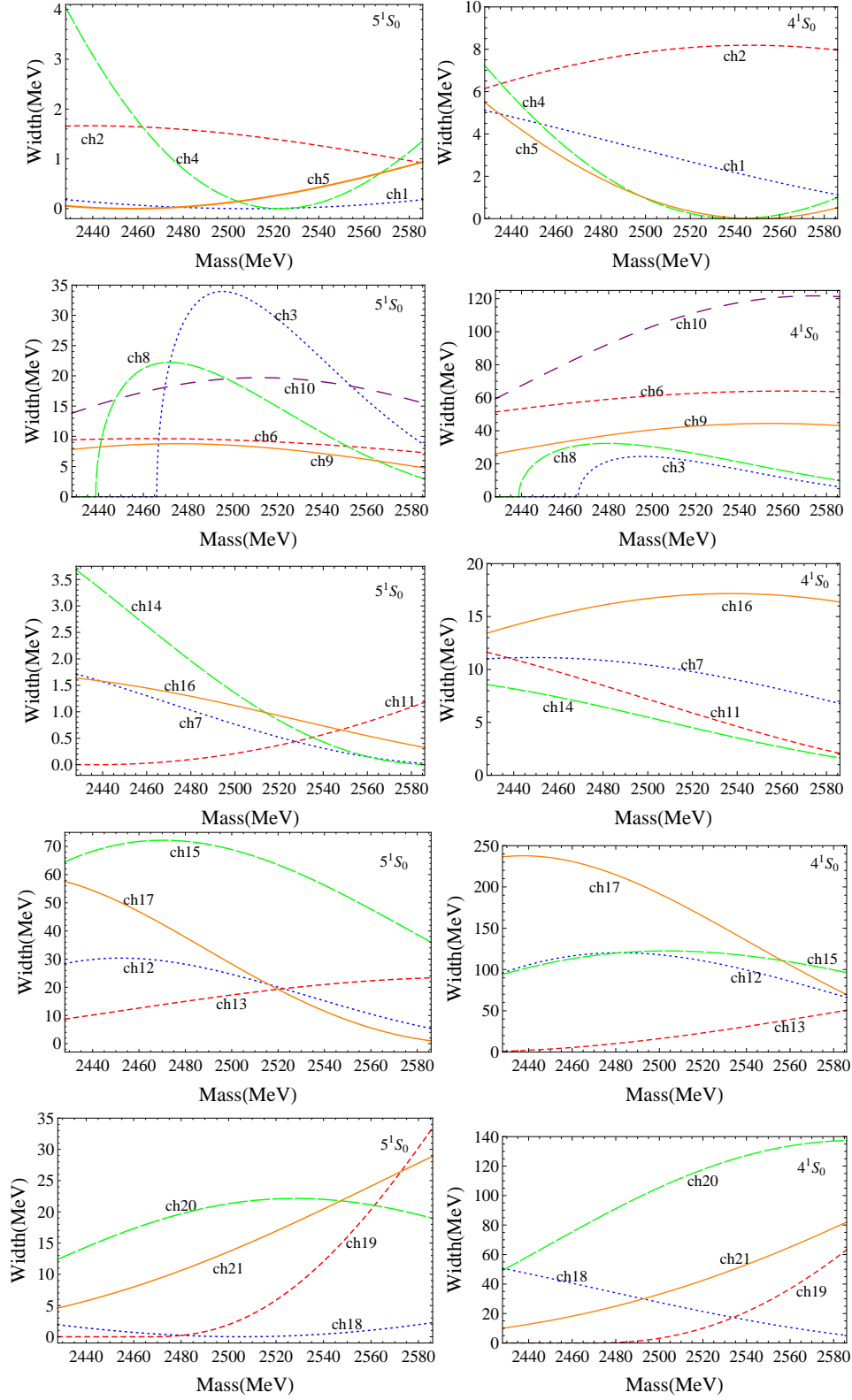


FIG. 4: The dependence of the partial widths of the 5^1S_0 (left panels) and 4^1S_0 (right panels) $s\bar{s}$ states on the initial state mass in the 3P_0 model. The curves labeled "ch*i*" stand for the results of the *i* decay channels of Table I.

$K^*K(1460)$, $KK_0^*(1950)$, $K^*K_2^*(1430)$, $\eta(1475)f_0(980)$, and $K^*K_1(1400)$ are needed.

In addition, the accurate mass spectra of the high radial excited meson and strong decay properties of the pseudoscalar glueball can improve our understanding the $X(2500)$.

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